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This report covers the period from November 1, 1965 to April 30, 1966, during which research was performed under National Aeronautics and Space Administration Grant NsG-419. Progress in the principal areas of investigation is briefly reviewed below.

1. K-band Radiometry and Observations

Measurements of Venus, Jupiter, the sun, moon, Taurus A, and 3C273 were made during the period from January to March, 1966 at wavelengths of 1.18, 1.28, 1.35, 1.43, and 1.58 centimeters. The five-channel Dicke radiometer and 28-ft. antenna were essentially those described earlier. The major additions to the system were i.f. gain modulators to permit separate balancing of each channel, and a new antenna feed to permit operation at lower frequencies.

The preliminary results indicate the average spectrums of Venus and Jupiter exhibited no resonant features at the 1.35-cm wavelength water vapor resonance. A complete analysis of the data is underway and will be reported at the 122nd Meeting of the American Astronomical Society in Ithaca, New York, July 25-28, 1966.

During the January - March, 1966, observing interval observations were also made of 36 sunsets to determine atmospheric attenuation on the water vapor resonance. Thirty-three of these observations were accompanied by radiosonde data from launches at Hanscom Field, Bedford, or M.I.T., Cambridge. These data are still being processed at this time.

A special K-band system has been constructed to attempt to detect stratospheric water vapor by virtue of the enhanced emission in a small frequency interval near the 1.35-cm resonance. This apparatus has been completed and is being packaged for outdoor use.

II. Oxygen-Line Observations at High Altitudes

The data taken during the balloon flights in July, 1965, have been reduced. The data are generally consistent with that taken during previous balloon flights. The theoretical antenna temperatures agree with the measured values for low heights, where both are equal to the atmospheric temperature because the optical depth is large for all channels. The antenna temperatures of the 200 Mc/s channels are the first to depart from the atmospheric temperature at about 18-20 km; the antenna temperatures of the 60 Mc/s and 20 Mc/s channels do likewise at about 22-24 km and 28-30 km, respectively.

Differences between the measured and theoretical valves are evident. On the 200 Mc/s and 60 Mc/s channels the measured antenna temperatures are higher than predicted above the height where departure from the atmospheric temperature occurs; whereas the 20 Mc/s channels behave approximately as predicted by theory. These results would appear to indicate a higher absorption than predicted at $\pm$ 200 Mc/s and $\pm$ 60 Mc/s from the resonance frequency and an absorption equal to the predicted value at $\pm$ 20 Mc/s from the resonance.

The discrepancy may lie in the theoretical assumption that the absorption coefficient due to many overlapping resonance lines is the sum of the individual absorption coefficients. There has been some evidence that this is not the case in the wings of overlapping lines, but that the true absorption coefficient is larger than the sum of the individual ones.

Analysis of the data from flight 154-P continues; in particular an inversion method yielding the absorption coefficient at various heights for each of the channels is being developed. This information will make interpretation in terms of correct line shapes much easier.

The results of flights 152-P and 153-P are being analysed with emphasis on inverting the microwave antenna temperature measurements to obtain the atmospheric temperature profile in the 16-38 km height range.

Another series of balloon flights was undertaken in January-February, 1966 from Phoenix, Arizona. The purpose of these flights was similar to that for flights 152-P and 153-P, namely to make microwave measurements which could be interpreted to yield the atmospheric temperature profile for a given height range. The flight characteristics and comments are summarized in Table 1.

TABLE 1 Summary of Winter Balloon Flight Experiments

Flight	Date	Duration	Float Altitude	Comments
198-LP	27 Jan.	8 hr.	38 km	Successful
199-LP	2 Feb.	1 1/2 hr.	none	Beacon Failure
200-LP	3 Feb.	8 hr.	39 km	Successful

The radiometer was modified slightly to give a better spread of weighting functions and to probe as deeply as possible for frequencies centerred on the 9+ resonance line. The radiometer parameters and the height levels sounded by these experiments are summarized in Table 2.

<u>TABLE 2</u> Summary, Flights 198LP, 199LP, 200LP

ν_o = 61.1506 Gc/s (Local oscillator frequency)

ΔT_{rms} 1-2°K

ν_{if} = center frequency of IF passband

BW_{if} = band width of IF passband

h_o = height of weighting function maximum

Δh = width of weighting function

T_B = brightness temperature predicted from model atmosphere

Θ = angle of antenna direction (from nadir)

Θ (deg)	ν_{if}(Mc/s)	BW_{if}(Mc/s)	h_o(km)	Δh(km)	T_B(°K)
75	20	10	37	7	258
0	20	10	32	10	246
75	60	10	29	8	244
0	60	10	25	9	230
75	275	24	22	7	222
0	275	24	17.5	8	218

Analysis of this data is underway.

Future flights are planned for the summer of 1966. Major changes to the radiometer are being made; the local oscillator frequency is being changed to 64.678 Gc/s, the 21+ resonance which is much weaker than the 9+ resonance, and the three IF's will be operated simultaneously rather than singly. The new frequency will permit weighting functions that penetrate the tropopause to give inversion methods a real test. The radiometer parameters and the height levels sounded by these experiments are summarized in Table 3.

TABLE 3 Summary, Summer, 1966 Flights

$\nu_o = 64.678$ Gc/s

$\Delta T_{ems} \cong 1\text{-}2^\circ K$

θ (deg)	ν_{if}(Mc/s)	BW_{if}(Mc/s)	h_o(km)	Δh(km)	T_B($^\circ$K)
75	20	10	29	12	231
75	60	10	22	12	218
75	275	24	16	9	214
0	20	10	14-25	23	225
0	60	10	13	15	224
0	275	24	12	11	227

The early results of this program have been documented and accepted for publication in the Journal of Geophysical Research.

III. Atmospheric Absorption at 72 Gc/s

An experiment to measure the atmospheric opacity at 72 Gc/s was performed to investigate absorption on the wings of the millimeter resonance lines of molecular oxygen. Solar extinction measurements were made with the 4 mm radiometric system on the roof of building 26 at M.I.T. Radiosonde measurements of the temperature, pressure, and water vapor density profiles were obtained from the Aerospace Instrumentation Laboratory at AFCRL for the days of the observations.

On a clear day the total atmospheric opacity, τ, at 72 Gc/s will be the sum of the opacities due to molecular oxygen absorption and water vapor absorption.

$$\tau = \tau_{O_2} + \tau_{H_2O} \tag{1}$$

Generally τ_{H_2O} is on the order of 1/3 - 1/2 of τ_{O_2} at this frequency for typical winter atmospheres. For each of the days of observation theoretical values of the opacity, based on the radiosonde data, were computed for comparison with the measured opacities. The opacity due to water vapor absorption was computed using the absorption coefficient of Barrett and Chung[1] as modified by Staelin[2]. Two separate oxygen opacities were computed for each observing day. One used the resonance line shape of Van Vleck and Weisskopf[3]

$$F_{VV-W}(\nu,\nu_o,\Delta\nu) = \frac{\nu}{\pi\nu_o} \quad \frac{\Delta\nu}{(\nu-\nu_o)^2 + \Delta\nu^2} + \frac{\Delta\nu}{(\nu+\nu_o)^2 + \Delta\nu^2} \tag{2}$$

for each of the millimeter resonance lines of oxygen; while the other used the line shape of Zhevakin and Naumov[4]

$$F_{Z-N}(\nu,\nu_o,\Delta\nu) = \frac{4\nu\ \nu_o}{\pi} \qquad \frac{\Delta\nu}{(\nu^2-\nu_o{}^2)^2 + 4\ \nu^2\ \Delta\nu^2} \tag{3}$$

The expression for the line width parameter, $\Delta\nu$, appearing in both the line shape expressions was taken as that of Meeks and Lilley[5].

Table 1 shows the measurements compared to each of the theoretical computations.

TABLE 1 Atmospheric Opacities

$$\tau_{VV-W} = \tau_{O_{2_{VV-W}}} + \tau_{H_2O}$$

$$\tau_{Z-N} = \tau_{O_{2_{Z-N}}} + \tau_{H_2O}$$

Date	τ measured (db)	τ_{VV-W}(db)	τ_{Z-N}(db)
18 March 1966	1.71 $\pm$ 0.15	2.09	1.83
21 March 1966	1.29 $\pm$ 0.21	1.94	1.66
29 March 1966	1.37 $\pm$ 0.17	1.67	1.35
4 April 1966	1.65 $\pm$ 0.23	1.84	1.59
15 April 1966	1.62 $\pm$ 0.19	1.94	1.68

The measurements appear to be in fairly good agreement with the computations based on the Zhevakin-Naumov line shape. It is possible, however, to explain the measured results within the context of the Van Vleck-Weisskopf line shape if the line width parameter, $\Delta\nu$, is taken as 0.85 of the value used in the computations. At the pressures of interest this is not an unreasonable value for $\Delta\nu$.

Atmospheric opacity measurements both above and below the 60 Gc/s complex of oxygen lines are suggested to resolve the above conflict. The line shape difference is an asymmetric one with the VV-W line shape giving more absorption above the resonance and less below it than the Z-N line shape; whereas a smaller Δv gives less absorption both above and below the resonance.

In addition recent laboratory measurements of the millimeter and sub-millimeter water vapor lines should be incorporated into a more accurate expression for absorption at frequencies near 72 Gc/s.

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IV. Radio Detection of Interstellar $O^{18}H^1$

Previous radio observations of interstellar OH have been due to the most abundant isotopic species $O^{16}H^1$. These observations have allowed the computation of the detection possibilities and accurate line frequencies of the isotopic species $O^{18}H^{1}$ (Ref. 1). In particular, the $F = 2\rightarrow 2$, ${}^{2}\pi_{3/2}$, $J = 3/2$, Λ- doublet transition was calculated to occur at 1630.3 ± 0.2 Mc/s. We have observed this line in the absorption spectrum of the galactic center (Sagittarius A) using the 140-foot radio telescope of the National Radio Astronomy Observatory. The observations were conducted during April 30-May 4, 1966, and consisted of a total of 18 hours of integration. The observations reveal absorptions of approximately 0.4°K and 0.1°K at radial velocities of + 40 Km/s and - 135 Km/s, respectively, if the rest frequency is taken to be 1639.460 Mc/s. The velocities of absorption are in excellent agreement with those of $O^{16}H^{1}$ (Ref. 2), and the rest frequency agrees very well with the predicted value. A spectral width of 2.0 Mc/s was the maximum that could be examined within our assigned time on the antenna. This also precluded making observations of the line expected at 1637.3 ± 0.2 Mc/s which might be as much as a factor of two less intense and, therefore, require four times as much observing time for the same signal-to-noise ratio.

The theoretical r-m-s noise for 18 hours of integration is 0.03°K and it is apparent that this valve is almost realized. Severe problems arise in spectral line radiometers when very long integration times are involved. A dual switching technique to eliminate instrumental effects was used. First, a load switching technique was used on each hour of observation and the correlator computed the difference in autocorrelation functions looking at the antenna and then at the load. Then for each hour of observation the local oscillator was shifted to displace any signal from Sagittarius A by 250 Kc/s, from the previous position in a three position cycle. The data was then averaged by shifting the spectra appropriately so that the signals line up in frequency. The data was also averaged using shifts opposite to those required to line up the signal data. The differences of the two averages was then taken and compensation made for the smeared signal data in the reference spectrum. This last technique eliminated any instrumental spectra from the correlator which amounted to several degrees. The instrumental effect in the correlator was due to errors in the sampler not being entirely random and independent of the load switching cycle. However this combination of load and frequency switching may always be desireable for long integration times even with improved samples performance.

It is difficult to estimate the O^{18}/O^{16} isotopic abundance ratio from the results of the observations because of some uncertainty in the interpretation of the $O^{16}H^{1}$ absorption. Robinson et. al. give an $O^{16}H^{1}$ optical depth of 0.9 for the +40 Km/s absorption feature in Sagittarius A,[3] and similar arguments can be used to infer an optical depth of 0.35 for the -135 Km/s feature using the more recent observations of Bolton et. al.[2] Our observations can be interpreted in terms of $O^{18}H^{1}$ optical depths of 2×10^{-3} and 5×10^{-4} for the + 40 Km/s and -135 Km/s features, respectively. If we make the plausible assumption that the $O^{18}H^{1}$ and $O^{16}H^{1}$ dipole matrix elements are the same, and the more uncertain assumption that the $O^{18}H^{1}$ and $O^{16}H^{1}$ optical depths are in the direct ratio of the O^{18}/O^{16} abundances, then we derive O^{18}/O^{16} isotopic abundance ratios of 1/450 and 1/700 for the two absorption features. These are in good agreement with the terrestrial abundance ratio of 1/490. Departures of the interstellar ratios from the terrestrial value could easily be explained by the uncertainty in the observed data, interpretation of the $O^{16}H^{1}$ observations, or different excitation and/or formation mechanisms for the two isotopic species of OH. To the best of our knowledge, the observations yield the first measure of any isotopic abundance ratios for the interstellar medium.

We wish to acknowledge the cooperation of personnel of the National Radio Astronomy Observatory and the use of the 140-foot radio telescope for our observations. The results of this research will be presented at the 122nd Meeting of the American Astronomical Society in Ithaca, New York, July 25-28, 1966.

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